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DESIGN OF FIRE EARLY DETECTION SYSTEM USING MICROCONTROLLER AS SMOKE AND SPRINKLE DETECTION USING FUZZY MAMDANI LOGIC METHOD

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ABSTRACT

This research presents the design of a fire early detection system utilizing a microcontroller integrated with Mamdani fuzzy logic. The system employs multiple sensors, including temperature, gas, and infrared sensors, to detect fires by analyzing the temperature, gas concentration, and fire distance. The microcontroller serves as the core processor that controls the sensors and triggers responses, such as alarms and sprinkler activation, based on fuzzy logic-based decision-making. Fuzzy logic enhances the system's adaptability to different fire severity levels, improving response accuracy. The system successfully detects potential fires, controls the sprinkler system automatically, and is shown to improve fire prevention in various environments. Testing results indicate that the system can effectively identify fire hazards and minimize damage by responding appropriately to various fire scenarios. This research provides a foundation for developing smarter and more efficient fire safety systems.

KEYWORDS *Fire Detection System, Microcontroller, Mamdani Fuzzy Logic, Automatic Sprinkler, Fire Prevention, Smart Fire Control.*

INTRODUCTION

In the era of modern technology, designing a fire early detection system is very important to protect buildings and human lives from the threat of fire that can occur at any time. Fire is one of the disasters that can cause huge losses, both in terms of material and casualties. Therefore, the development of a fire early detection system is the main focus in order to prevent and reduce the impact of fires. In this research, a fire early detection system is designed using a microcontroller as a

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smoke detector and sprinkler with a *fuzzy* logic method to increase the efficiency and accuracy of detection and system response (Ishfahani, 2018).

Microcontrollers are small electronic components but have high data processing capabilities. In designing a fire early detection system, a microcontroller is used as the brain of the smoke detection system. The microcontroller can be connected to a smoke sensor that is sensitive to smoke particles produced during a fire. This sensor will send a signal to the microcontroller when it detects a concentration of smoke that exceeds the threshold. The microcontroller will process the signal and make a decision whether a fire is occurring or not (Wibowo and Pernata, 2020).

Fuzzy logic methods are used in fire early detection systems to overcome the uncertainty and complexity of information from the surrounding environment. *Fuzzy* logic allows the system to make decisions based on the degree of membership of a condition in a certain category. In this context, the *fuzzy* logic method is applied to the results of data processing from smoke sensors. The system will assess the severity of the fire based on the level of smoke concentration detected. With *fuzzy* logic, the system can provide a more adaptive response to diverse fire situations (Anam *et al.*, 2020).

In addition to early detection, this system also involves the use of sprinklers as the first step in handling fires. Sprinklers are devices that can emit water automatically when a fire is detected. The integration of the early detection system with sprinklers through microcontrollers and *fuzzy* logic enables smarter settings in activating sprinklers. For example, if the severity of the fire is low, the system can trigger only a few sprinklers to extinguish the fire, while if the fire is large enough, all sprinklers will be activated." (Setyawan *et al.*, 2021)

Designing a fire early detection system using a microcontroller and *fuzzy* logic method has the potential to improve efficiency, accuracy, and response in handling fires. This system can reduce losses caused by fires by detecting and tackling fires at an early stage. The advantage of this system lies in its ability to make decisions based on uncertain and complex information, making it reliable in various situations. It is hoped that the results of this research can contribute to the development of a more reliable and effective building security system against the threat of fire. (Mohammad Narji *et al.*, 2022).

This research aims to integrate smoke sensors with microcontrollers to detect the presence of smoke due to fire and apply fuzzy logic to analyze smoke detection data, so as to determine the severity of the fire. In addition, this research also focuses on setting up a sprinkler system based on fuzzy logic analysis to provide an appropriate handling response to the fire situation that occurs.

Through this research, it is expected to create an efficient and accurate smoke detection system, as well as a fuzzy logic model that is able to better assess the severity of the fire. The integration of the early detection system with sprinkler control is expected to increase the responsiveness and accuracy in detecting and dealing with fire threats, especially in the home and other building environments (Hillah *et al.*, 2022).

Previous research aims to obtain comparison and reference materials. In addition, to avoid similarities with this research. So in this previous study, researchers listed the results of previous studies.

1. Previous research conducted by (Jumadril and Arnomo, 2022). This research develops a prototype design of this automatic fire extinguisher using an Arduino Uno atmega328p microcontroller based on *fuzzy* logic.
2. Other research conducted by (Fitriadi *et al.*, 2022). This research aims to design an early fire prevention system in a room with a *fuzzy* logic method based on the Internet of Things (IoT). The system consists of inputs in the form of fire sensors, smoke sensors, and temperature sensors. *Fuzzy* logic with Mamdani inference can detect a potential fire with an average error of less than 1% when compared to MATLAB simulation results.
3. In research conducted by (Anam *et al.*, 2020). In this study using three sensors, namely the fire sensor, temperature sensor, and smoke sensor as a source of data input. Arduino devices as data readers and Raspberry Pi are in charge of managing further data. While the method used to detect fires is the *Fuzzy* Sugeno method with three main parameters, namely temperature, smoke density, and fire intensity.
4. In research conducted by (Simbolon *et al.*, 2020). In this study, a building fire detection prototype was made using Arduino mega 2560 with DS18B20, MQ-2, flame sensor and buzzer sensors as alarms. *Fuzzy* logic is used to determine an appropriate condition in a building whether it is dangerous or not which later the buzzer will sound according to the *fuzzy* output results. In the *fuzzy* logic algorithm, an accuracy of 99.995% is obtained. For the average delay value of the tool to the thingspeak database of 41.249 ms and for the average throughput value obtained of 14.732 Kbps.

Based on previous studies, the weaknesses and advantages of previous approaches in fire early detection can be identified, as well as the potential for applying *fuzzy* logic methods in improving the performance and adaptability of fire early detection systems that use microcontrollers as smoke detectors and sprinklers. The development of a fire early detection system that uses microcontrollers as smoke detectors and sprinklers with the application of *fuzzy* logic methods has the potential to improve the efficiency, accuracy, and response of the system in dealing with fire threats. This technology integration is expected to produce a more adaptive and intelligent solution in dealing with various fire scenarios that may occur.

RESEARCH METHOD

This research framework describes the sequence of activities to be carried out in research related to fire early detection systems using microcontrollers and fuzzy logic. The research begins with a literature study to understand relevant theories and technologies, including fire detection systems, Internet of Things (IoT), Arduino, and fuzzy logic (Devi, 2019). Next, a system requirements analysis was conducted to determine the required inputs, processes, and outputs. Inputs include data from smoke and temperature sensors, while outputs include fire detection decisions, severity, sprinkler control, and alarm and notification signals. Fuzzy logic is used to process this data and generate intelligent decisions (Adhiluhung *et al.*, 2022).

The design process involves interfacing hardware components with the NodeMCU microcontroller as well as software development to ensure proper integration. Once the system is designed, testing is conducted to ensure the functionality and reliability of the system before it is deployed in a real environment (Alkawiyu *et al.*, 2021). The research discussion plan includes the utilization of IoT and fuzzy logic in improving home security, analysis of test results, and potential for further development. The research is scheduled to take place from May 2023 until completion (Saiyar and Rudianto, 2022).

RESULT AND DISCUSSION

Hardware Design

The hardware design system that will be discussed is shown in the hardware system diagram blog below:

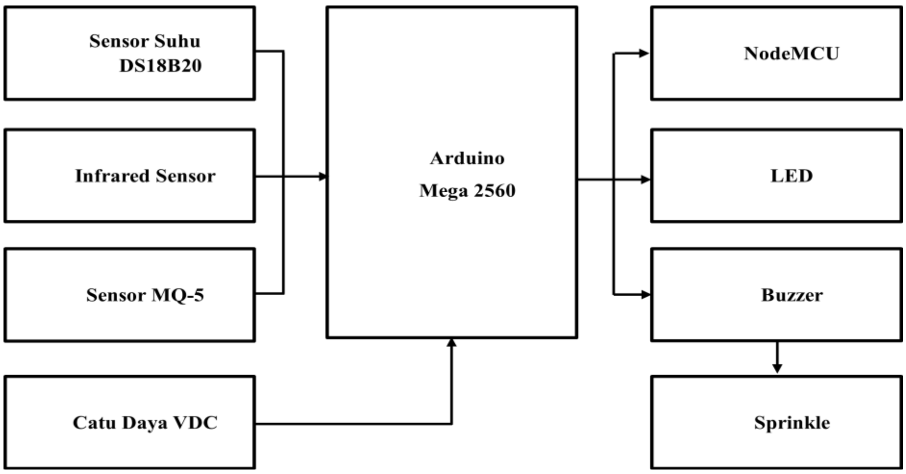


Figure 4. 1 Hardware Blog Diagram

In the blog diagram, it can be explained that the design of this tool consists of several components that can make the system run according to its purpose, namely the Temperature Sensor which functions as a receiver of temperature data, the MQ-5 Sensor which functions as a receiver of Smoke data, Infrared Sensor which functions as a receiver of Fire data, Arduino Uno as a data processor received from DS18B20 and MQ-5, after which the data received from the sensor is processed by a microcontroller to turn on the buzzer, led, and NodeMCU as a Wifi Module.

Sensor Testing

The purpose of this testing process is to determine the level of accuracy of the temperature sensor. In the process of testing the MQ-5 gas sensor, five stages of testing were carried out, namely the first test was carried out by measuring room gas levels, second measuring lighter gas levels, third measuring plastic smoke concentration, fourth measuring paper smoke concentration, last measuring plastic smoke concentration. In each test, the PPM value will be calculated based on the following equation (Gull *et al.*, 2021).

$$PPM = \frac{Range}{bit\ ADC} \times ADC$$

Table 4.1 shows the test results of the MQ-5 gas sensor for five gas scenarios. Based on the test results, the PPM value is directly proportional to the ADC value generated by the sensor. The lowest PPM value is generated in the room gas scenario which is 407 ppm, while the highest PPM value is detected in the cigarette smoke scenario which is 791 ppm. Thus it can be concluded that the MQ-5 gas sensor has been able to work well where it is able to detect various test gas scenarios.

Table 4.1 MQ-5 sensor test results

No.	Conditions	MQ-5 sensor value	
		ADC	PPM
1	Room	209	407
2	Matches	370	721
3	Plastic Smoke	338	659
4	Paper Smoke	350	682
5	Cigarette Smoke	406	791

The testing process on the fire sensor aims to test the performance of the sensor when detecting fire sources within a distance of 10-100 cm. In testing this sensor using a candle fire source placed parallel to the fire sensor. If a fire source is detected, the fire sensor indicator light will turn on and vice versa if no fire source is detected, the indicator light on the sensor will turn off.

Table 4.2 Infrared Sensor test results

No.	Distance(cm)	Sensor Indicator
1	10	ON
2	20	ON
3	30	ON
4	40	ON
5	50	ON
6	60	ON
7	70	ON
8	80	ON
9	90	ON
10	100	OFF

Table 4.2 shows the test results of the fire sensor for 10 trials. Based on the test results, it is found that the fire sensor is able to detect a fire up to a distance of 100 cm. However, for implementation on a real scale, a fire sensor that is able to detect a greater distance is needed so that fire detection can be done optimally.

Monitoring System Testing

The next testing process is testing data transmission connected to one network between the *Smartphone* and Arduino. This system still uses a *server* on the *website* and Blynk application by sending DS18B20 temperature sensor data, MQ-5 gas sensor, and fire sensor (Dewanata *et al.*, 2021). The test results of the monitoring display on the Blynk application are shown below.

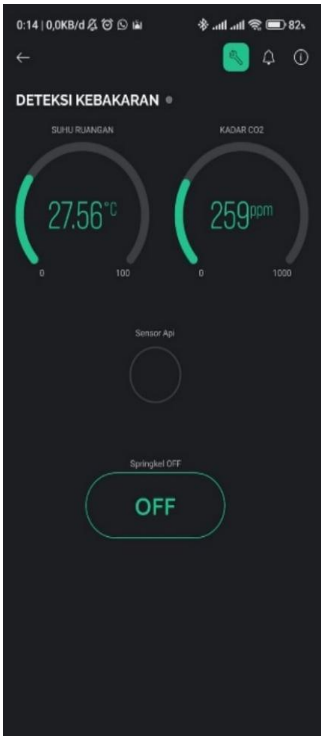


Figure 4. 2 Initial user interface

There is a Temperature panel, Oxygen level or ppm, Fire Sensor, and Off button for Sprinkle.

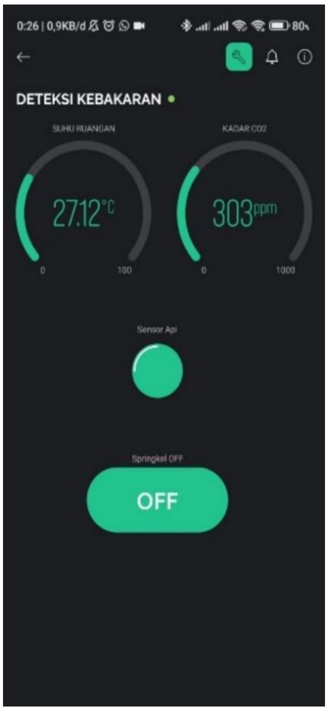


Figure 4. 3 Fire Detected Display

The Fire Sensor will turn on in the Blynk app when a fire is detected at a distance of less than 100 cm.

Figure 4. 4 Alert view

When the oxygen level reaches >850 and the temperature >40, an Alert warning notification will appear, which means that you must be careful because the surrounding area has detected thick enough smoke to allow a fire to occur.

Figure 4. 5 Dangerous display

When oxygen levels reach >850 and temperatures >65 a Dangerous warning notification will appear, and the Buzzer will sound then the sprinkle will spray water due to the detection of thick smoke pressure and high temperatures by the MQ-5 gas sensor and the fire sensor.

Figure 4. 6 Alert History View

Displays the history results that have been read when the sensor reads the blynk application system data on the *smartphone*.

Fuzzy logic testing

At this stage of the testing process, testing of the *fuzzy* logic system is carried out by comparing the results of *crips* between MATLAB *software* and the tools that have been made (Gulo *et al.*, 2022).

1. Variable Input

Table 4.3 Input Data from Arduino

No.	Sensor input		
	Temperature (°C)	Gas (ppm)	Fire (cm)
1	29,62	355	0
2	31,38	276	0
3	40,69	620	100
4	44,69	600	100
5	42,62	666	100
6	40,06	717	100
7	40,12	724	100
8	37,5	813	100
9	46,62	829	100
10	46,19	846	100

2. Fuzzyfication

A membership function is a curve that shows the mapping of input data points into their membership values (often called membership degrees) which have an interval between 0 and 1.

Membership functions for temperature:

Table 4.4 Temperature Value

Temperature	**Value**
Normal	0-45
Hot	30-60
Very Hot	45-100

Normal Temperature
if 0 < temperature <= 45
μNormal = (45 - temperature) / 45
Hot Temperature
if 30 < temperature <= 45
μHeat = (temperature - 30)/(45 - 30)
if 45 < temperature < 60
μHeat = (60 - temperature)/(60 - 45)
Extremely Hot Temperature
if 45 < temperature <= 100
μHeat = (temperature - 45)/(100 - 45)
Manual Fuzzyfication Calculation:
Normal Temperature(1) = 29.62
if 0 < 29.62 <= 45
= (45 - 29.62) / 45
= 15.38 / 45
= 0.341

Table 4.5 Fuzzy Membership Values Temperature

No.	Temperature (°C)	μNormal	μHeat	μVery Hot
1	29,62	0.341	0	0
2	31,38	0.302	0	0
3	40,69	0.095	0,712	0
4	44,69	0.006	0,979	0
5	42,62	0.052	0,841	0
6	40,06	0.109	0,670	0
7	40,12	0.108	0.674	0
8	37,5	0,166	0	0.118
9	46,62	0	0.892	0.029
10	46,19	0	0.920	0.021

Membership functions for gas:

Table 4.6 Gas Value

Gas	Value
Thin	0-600
Medium	400-800
Thick	600-1000

Thin Gas
if gas ≤ 400
µThin = 1
if 400 < gas ≤ 600
µThin = (600 - gas) / (600 - 400)
Medium Gas
if 400 < gas <= 600
µMedium = (gas - 400) / (600 - 400)
if 600 < gas <= 800
µModerate = 1
if 800 < gas <= 1000
µMedium = (1000 - gas) / (1000 - 800)
Thick Gas
if 600 < gas <= 800
µThickness = (gas - 600) / (800 - 600)
if gas > 800
µThickness = 1
Manual Fuzzyfication Calculation:
Gas(1) = 340
if 340 < 400
= 1

Table 4.7 Fuzzy Membership Values Gas

No.	Gas (ppm)	µThin	Medium	µThick
1	355	1	0	0
2	276	1	0	0
3	620	0	1	0.1
4	600	0	1	0
5	666	0	1	0.33
6	717	0	1	0.585
7	724	0	1	0.62
8	813	0	0.935	1
9	829	0	0.855	1
10	846	0	0.77	1

Membership functions for api:

Table 4. 8 Fire Value

Fire	Value

Near	0-45
Medium	20-70
Deep	45-100

Near Fire
if api == 0
μNear = 1
if 0 < fire ≤ 45
μNear = (45 - fire) / (45 - 0)
Medium Fire
if 20 < api <= 45
μMedium = (fire - 20) / (45 - 20)
if 45 < api <= 70
μMedium = (70 - fire) / (70 - 45)
Distant Fire
if 45 < api <= 100
μFar = (fire - 45) / (100 - 45)
Manual Fuzzyfication Calculation:
Near Fire (1) = 0
if 0 == 0
= 1

Table 4. 9 Fuzzy Membership Values of Fire

No.	Fire (cm)	Near	Medium	Deep
1	0	1	0	0
2	0	1	0	0
3	100	1	0	0
4	100	0	0	1
5	100	0	0	1
6	100	0	0	1
7	100	0	0	1
8	100	0	0	1
9	100	0	0	1
10	100	0	0	1

3. Inference

Fuzzy inference is a method that interprets the values in the input vector and, based on some set of rules, assigns values to the output vector. In fuzzy logic, the truth of a statement depends on a certain degree (Sefi Pujaningrum, 2021).

Based on the fuzzy rules, we can determine the membership value for each output set (Status Level).

a. If the Temperature is Extremely Hot and the Gas is Thick and the Fire is Distant), then the Status Level is Dangerous.
b. If the Temperature is Hot and the Gas is Medium and the Fire is Medium, then the Level Status is Alert.

c. If the Temperature is Normal and the Gas is Thin and the Fire is Close, then the Level Status is Normal.

Here we will calculate for the first data, according to the table below:

Table 4.10 Data 1 Temperature

No.	Temperature (°C)	µNormal	µHeat	µVery Hot
1	29.62	0.341	0	0

Table 4. 11 Data 1 Gas

No.	Gas (ppm)	µThin	Medium	µThick
1	355	1	0	0

Table 4. 12 Data 1 Fire

No.	Fire (cm)	Near	Medium	Deep
1	0	1	0	0

The data below is adjusted based on the value of the table above according to the rules that have been determined.

3. Defuzzification

We will calculate the defuzzification value using the centroid method.
Data Point 1:
Temperature = 29.62 (µNormal = 0.314, µHot = 0, µVery Hot = 0)
Gas = 355 (µThin = 1, µMedium = 0, µThick = 1)
Fire = 0 (µNear = 1, µMedium = 0, µFar = 0)
Inference:
Rule 1 applies with µ = min(0.314, 1, 1) = 0.314 -> Output: Normal
Rule 2 applies with µ = min(0, 0, 0) = 0 -> Output: Alert
Rule 3 applies with µ = min(0, 1, 0) = 0 -> Output: Dangerous

Thus, based on the manual calculations that have been carried out, with a temperature of 29.62 ° C, gas of 355 ppm, and a fire of 0 cm, the status level given is "Normal" with the highest defuzzification value of 0.314.

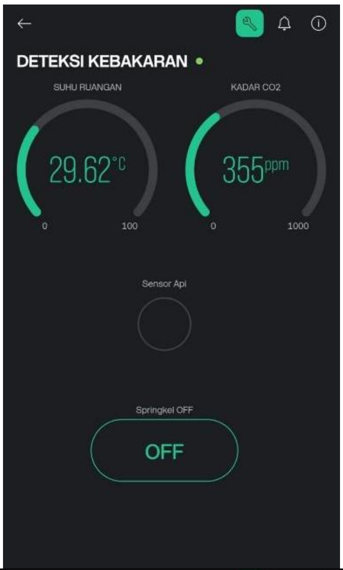
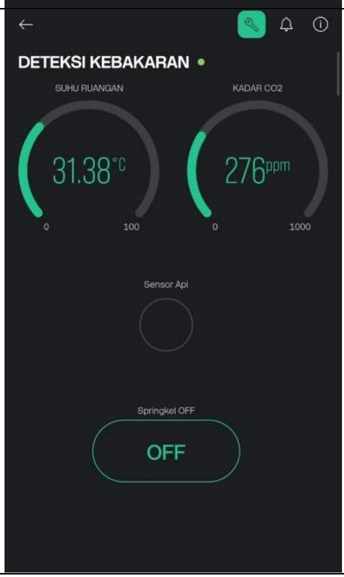
Data Point 2:
Temperature = 31.38 (µNormal = 0.302, µHot = 0, µVery Hot = 0)
Gas = 276 (µThin = 1, µMedium = 0, µThick = 0)
Fire = 0 (µNear = 1, µMedium = 0, µFar = 0)
Inference:

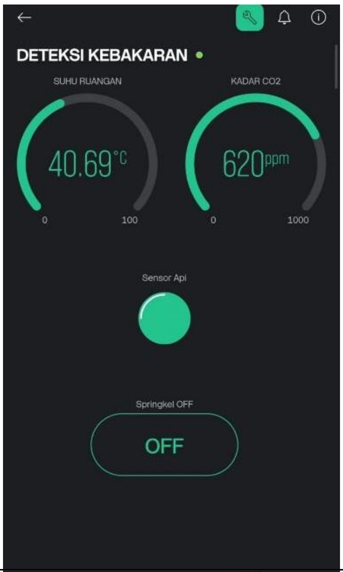
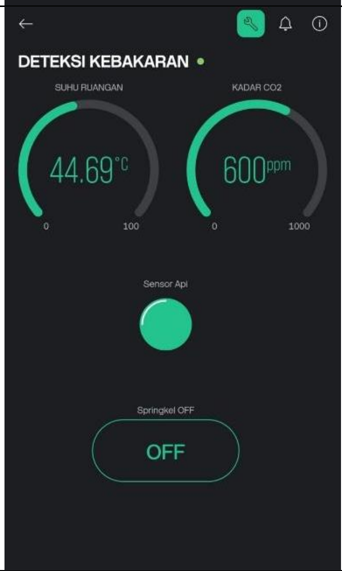
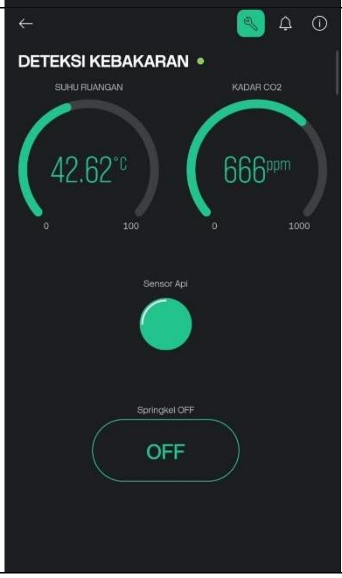
Rule 1 applies with µ = min(0.302, 1, 1) = 0.302 -> Output: Normal
Data Point 3:
Temperature = 31.38 (µNormal = 0.302, µHot = 0, µVery Hot = 0)
Gas = 276 (µThin = 1, µMedium = 0, µThick = 0)
Fire = 0 (µNear = 1, µMedium = 0, µFar = 0)
Inference:

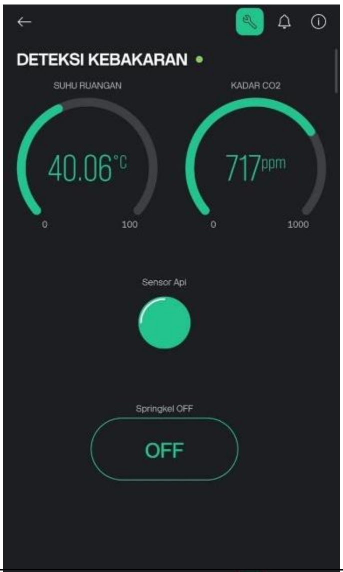
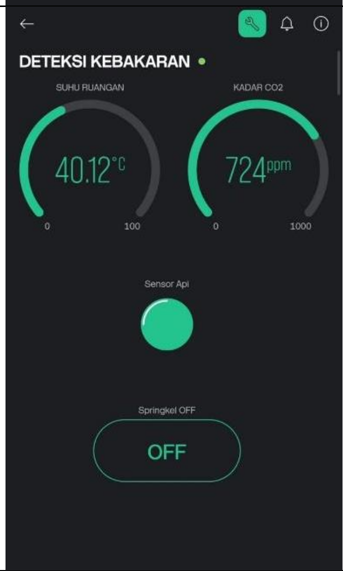
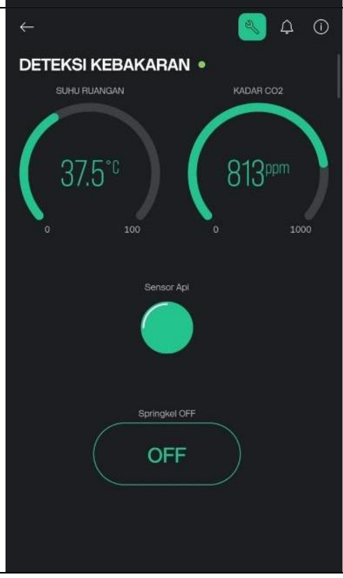
Rule 1 applies with μ = min(0.302, 1, 1) = 0.302 -> Output: Normal

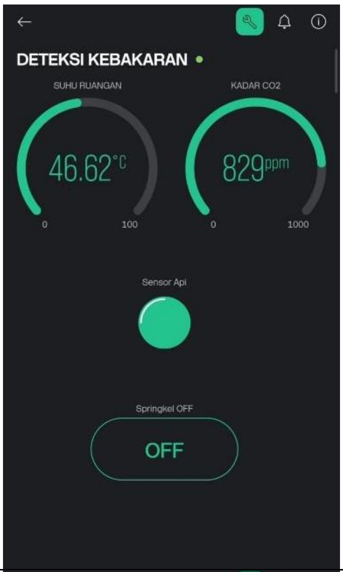
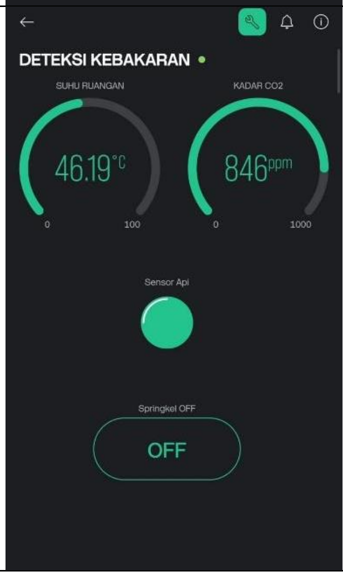
The goal is to ensure that the system that has been designed can work in accordance with the *fuzzy logic* algorithm in the Blynk application simulation. The table shows the test results on the Blynk application with a device that has been tested for 10 data.

Table 4. 13 Fuzzy Logic Table

No	Sensor input			Status Level	Testing Results
	Temperature (°C)	Gas (ppm)	Fire (cm)		
1	29,62	355	0	Normal	
2	31,38	276	0	Normal	

3	40,69	620	100	Alert	
4	44,69	600	100	Alert	
5	42,62	666	100	Alert	

6	40,06	717	100	Alert	
7	40,12	724	100	Alert	
8	37,5	813	100	Dangerous	

9	46,62	829	100	Dangerous	
10	46,19	846	100	Dangerous	

Based on the test results, it can be concluded that the *fuzzy logic* algorithm that has been designed can produce fire risk level status output in accordance with the display on the Blynk application.

CONCLUSION

This research concludes that the fire early detection system designed using microcontroller and Mamdani fuzzy logic method is proven effective in detecting fires through analyzing temperature variables, gas concentration, and fire distance. The system is able to provide fast and accurate responses, such as activating notifications, buzzers, and automatic sprinkles when detecting potential fires. The use of automatic sprinklers is proven to increase the effectiveness of the system in controlling fires at an early stage.

Suggestions for future research include further testing across different fire scenarios to ensure the reliability of the system under various conditions. Research is also recommended to optimize the fuzzy rules and consider hybrid approaches, such as neural networks or genetic algorithms, to improve detection accuracy. In addition, it is important to add a security layer to the system to protect data and communication, especially if the system is connected to the internet.

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